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Abstract

In response to increasing demands of incorporating sustainability concerns into a firm's supply chain management, firms should take actions that exceed their boundaries. As a consequence, firms have recognized the importance of adopting green practices and reducing a combination of different types of indicators, namely operational (e.g. product output, availability, costs), and environmental (e.g. energy consumption, carbon footprint). Within this context, this paper tries to assess the impact of ordering and truck loading policies on both transport costs and CO_2

emissions. The results indicate that bigger order batches can both decrease performance indicators and keep the inbound service level stable.

Keywords: Sustainable Supply Chain, Simulation, Environmental Performance, Order Patterns, Order Policy

1 Introduction

The dynamic character of today's competitive environment forces organizations to reconsider the principles existing across their supply chains. Within this context, the introduction of new methods in the general topic of sustainable supply chains has been of upmost importance.

As stakeholders' pressures (especially these originating from government regulators and global competition) strain, companies tend to adopt a certain level of commitment to environmental and sustainability practices (Hassini et al., 2012). However, these companies are lacking a common standard for evaluating sustainability metrics (Searcy et al., 2009) and some authors even argue that there exist some incompatibilities between the known principles of performance measures and supply chain dynamics (Lehtinen and Ahola, 2010). Thus, there is need for more research on sustainable practices and environmental measures across the supply chain (Bunse et al., 2011).

Nowadays, supply chains face many problems. One of the most significant is the ordering problem, which deals with the backwards abnormalities created to the supply chain, as a part of the bullwhip effect (Lee et al, 1997). Such irregularities tend to affect not only the manufacturing, but also the transportation. Thus, costs tend to become unstable and extremely high. The existence of information sharing and collaborative practices across the supply chain seem to be of the utmost importance in the solution of this problem.

All these factors related to the supply chain's performance are quite expensive to be tested in the real world. However, simulation is offered as an ideal tool which is not only costless, but also effective. Almost any supply chain issue can be simulated. In addition, simulation can easily incorporate uncertainty (Buckley and An, 2005) and give concrete answers to business scenarios.

This paper underlines the need for tools facilitating the environmental practices adoption in order to improve the supply chain environmental performance in an operational level. In this context, this is trying to give some answers to different experimental scenarios related to the impact of alternative order patterns on the supply chain environmental performance.

2 Literature Review

This section presents a brief overview of the existing literature of sustainable supply chains. By referring to a supply chain we mean all the parties involved in fulfilling a customer's order. In particular, we underline the fact that more than one decision maker is involved in managing resources, information and processes that may not be entirely under the control of their company (Chopra and Meindl, 2007). As this decision processes become more complex, the forms of information sharing tend to become more intense (Attaran and Attaran, 2007).

Business sustainability is referring to "the ability to conduct business with a long term goal of maintaining the well-being of the economy, environment and society" (Chopra and Meindl, 2007). Elkington (1997) is credited with popularizing the latter three dimensions, called the triple bottom line (TBL) principle (also known as the three pillars: profit, planet, and people).

Keeping in mind all the above mentioned, sustainable supply chain management is defined as the management of supply chain operations, resources, information, and funds in order to maximize the supply chain profitability while at the same time minimizing the environmental impacts and maximizing the social well-being (Hassini et al., 2012).

Sustainable supply chains are very significant in today's business environment. Eltayeb et al. (2011) have viewed that green supply chain initiatives have positive effect on the supply chain outputs, showing that ecodesign has significant positive effect on the four types of outcomes (environmental outcomes, economic outcomes, cost reductions, and intangible outcomes).

According to Seuring and Müller (2008), there are four dimensions that can be used to structure the overall debate on sustainable supply chains: (1) pressures and incentives, (2) measuring impacts, (3) supplier management and (4) supply chain management. These incentives play a major role in this structure because they determinate the outputs given of a sustainable supply chain. Moreover Hassini et al. (2012) have shown that there is a strong demand for indicators in this area and more complex indicators are required. Furthermore, they have illustrated the difficulty in developing innovative indicators to the unique needs of each organization. Thus, the need for further case studies in order to validate the metrics is more than obvious and more attention should be given to industry-specific research on sustainable supply chain management.

To sum up, companies have not the appropriate means and tools for environmental performance practices implementation. They lack of sophisticated measurement, analysis and control (Dietmair and Verl, 2009; Weinert et al., 2011) and they only monitor and report performance indicators.

3 Case Study

3.1 Case Study Description

The case examined refers to a project which aims to contribute to an energy-efficient supply chain by providing the system, services, collaboration platform and management tools. These will enable energy and carbon footprint data monitoring, management and sharing in order to support both operational and strategic decision making across the supply chain. The project specifically focuses on the consumer goods sector and emphasizes on industry adoption and quantifiable impact assessment.

In more detail, the proposed scenarios refer to the impact assessment across the supply chain. In this context, the purpose is to apply alternative ordering patterns in order to assess the impact in terms of energy consumption and carbon emissions related to these decisions.

3.2 Case Study Specifications

The AS-IS scenario models the business of supplier S with the retailer R. The key figures of the modeled network are as follows:

- 79 locations
    - 2 sites (a production site PS and a distribution centre DC)
    - 77 customers
- 158 SKUs (stock keeping units / trading units)
- Real retailer order data 2012:
    - 1,949 Orders for PS
    - 903 Orders for DC

However, after a detailed data analysis we have decided to make some simplifications for our research and to focus on two warehouses, one big (with 1048 order rows and 60 orders yearly) and a smaller one (with 185 order rows and 37 orders yearly). The time period examined is defined from 1/1/2012 to 31/3/2012.

Figure 1 – Simulation Model Specifications

4 Simulation Model

4.1 The Simulation Component

The simulation component designed in the context of the project aims to support the environmental impact assessment.

The project's platform is based on different technologies. The three main sub-components of the simulation component (simulation database, simulation kernel, and user interface) are using a subset of these technologies as well as a few additional software packages.

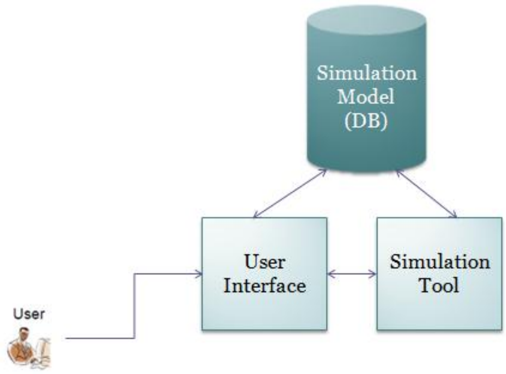

Figure 2 – Simulation Component's Architecture

4.2 The Simulation Data Model

Talking about supply chains requires data such as locations, transport relations, SKUs (Stock Keeping Units) and the information flow across the supply chain. In other words, a model is needed in order to describe better situation in the supply chain. The data model described below is referring to the inputs and the outputs of the simulation component in terms of entities and attributes. By entities, one can refer to general concepts, such as the customers and the SKUs of the model and by attributes to their special characteristics such as a customer's location or calendar and a SKU's description, weight or value.

4.2.1 Model Inputs

The platform contains two parts of input data: the Basic and the Configuration Data. The Basic Data contain information about the current supplier's supply chain and the stable data which can be divided into three main categories: locations, sourcing and routes. Locations include information about the sites' locations of the supply chain and the facts related to them, such as their address and their type (customer, supplier, warehouse etc). The second category refers to the sourcing of the supply chain and includes information about the SKUs (Stock Keeping Units) and their parts. Finally, the third and the last category of the basic data is related to the routes of the supply chain and it includes information about the transportation and the generated costs.

On the other hand, the Configuration Data describe the changeable parts of this supply chain and the scenarios designed and they are also divided into three categories: locations of the supply chain, SKUs and customer demand, sourcing across the supply chain. The first category depicts the different types of location that exist in the supply chain, while the second refers to the SKUs existing in the current scenario and to the customer demand. Finally, the last category illustrates the SKUs' sourcing across the supply chain.

4.2.2 Model Outputs

The simulation component offers some ready output tables for reporting which can be categorized into three big categories: SKUs' reporting, summary reporting and daily reporting. The first group provides us with outputs about SKUs' statistics, such as statistic information about the critical SKUs in the supply chain and the safety stocks. The second group contains aggregated information about the supply chain such as single cost categories and supply service levels. Finally, the third group depicts the supply chain over time and it contains daily information about some metrics, such as service level and means of transport.

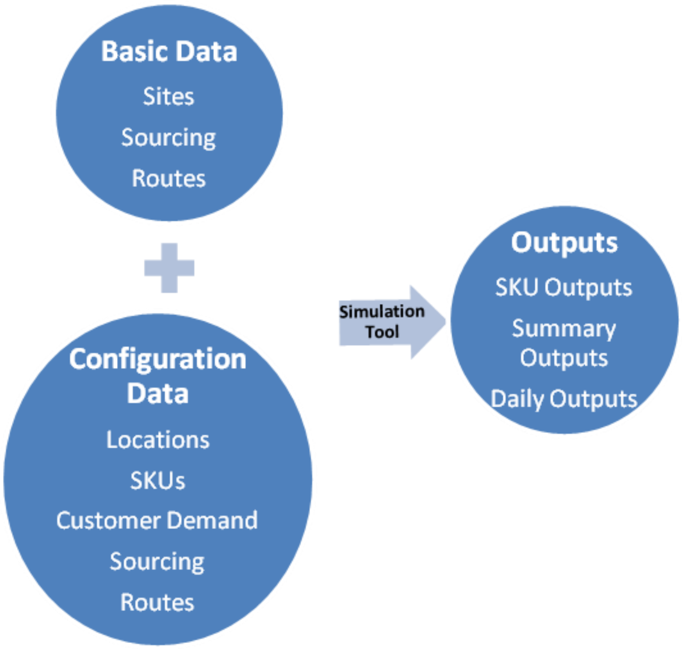

Figure 3 – Simulation Data Model

4.3 Design an Experiment

As mentioned above, the Configuration section of the data model allows one to design the scenarios.

The first part of this section consists of three components: Customers, Sites, Hubs and Plain Suppliers, which define the supply chain network. In the Customers' component we describe the retailers acting as customers including its location and the type of calendar they use. In the Sites' component one can define the production sites and the warehouses of the network and some information about the planning and the costs in these sites. In addition, in the Hubs and

Plain Suppliers component one can describe the other hubs and the suppliers of the including information about their planning and costs.

The second part describes the products existing in the supply chain. In the SKU (parts) component one can find information about the Stock Keeping Units, their characteristics, their location and the sourcing options. It also depicts production information. It consists of the SKU at Sites component, which contains information about the Stock Keeping Units in certain Sites. This information refers to the location and the usage of these SKUs, the stocks kept and the planning type used.

The third part of the Configuration Setup can provide somebody with information about the demand and consists of two components: Customer Demand and Customer Demand External. Customer Demand contains information about each customer's demand. It includes the SKUs ordered, the quantities, the variation and the distribution followed and the Site that services the certain customer. Moreover, Customer Demand External includes information about the orders each customer has made.

The fourth part consists of the Sourcing SKU component and refers to the central distribution of the products. This gives information about each SKU's distribution. It includes information about the production (e.g.lot size) and the delivery of each one (e.g. minimum order quantity).

Finally, the last part of the Configuration Setup refers to the decentralized customer service and consists of two components. Transport Planning shows the reliability of every option of transport planning (minimal, medium, maximum) and the Routes component includes data about the Routes that can be used for transporting. It also includes the costs and ways of routing and the constraints applied.

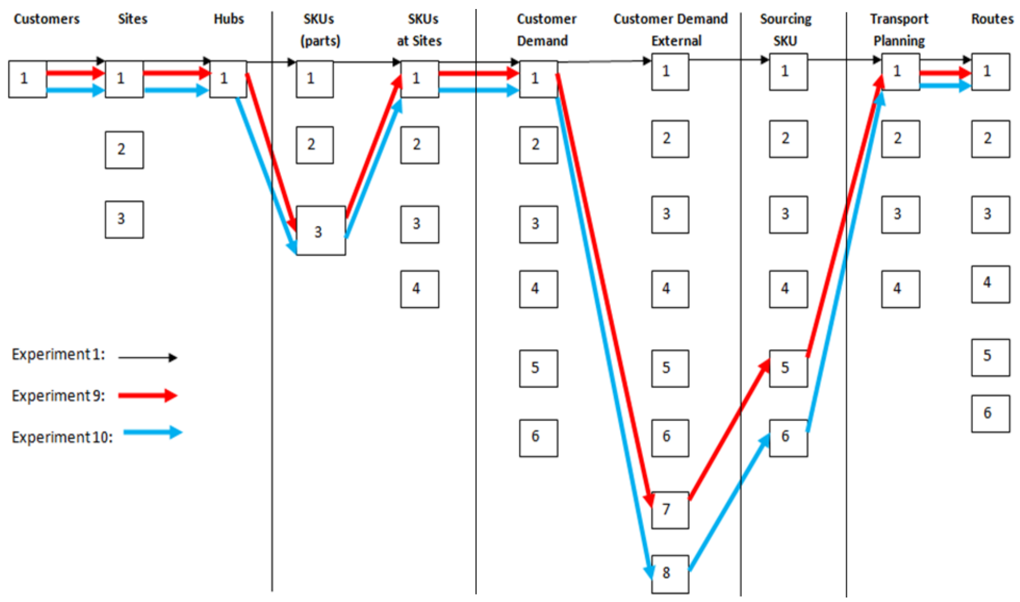

Figure 4 – Simulation Model Inputs in the Design of a Scenario

5 Experimental Design

5.1 Experimental Factors

As mentioned above, the method used in order to test the research hypotheses of this paper, is the simulation. Thus, we need to examine some determinant factors that in some way affect the outcomes and analyze their impact. In this phase, we have selected to test two specific variables: the level of minimum order quantity and the level of truck loading. Regarding the first of the two, we mean the minimum order size that is accepted by the supplier. This is applied in an order basis and, thus, all orders must be in multiples of this quantity. Regarding the level of truck loading, we mean the percentage of a truck's capacity that is filled before the truck starts transport. This factor is used in order to assure that no empty trucks are used across the supply chain. Combining these two variables, this can conclude in various different pairs of factors.

5.2 Performance Indicators

Apart from the experimental factors, performance indicators play a significant role. Within this paper, the indicators that we are going to examine are the transport costs and the CO_2 emissions. Transport costs are defined as the expenses involved in moving the products across the supply chain and they are computed as the product of the pallets transported in each route multiplied with the freight cost of this route. CO_2 emissions include the carbon dioxide emissions that accrue from the products' transportation. CO2 emissions' computation is based on the type of the means of transport used and is taking place for each pallet transported.

5.3 Conceptual Model

The Conceptual Model designed as a part of this paper depicts the business decisions that need to be taken as a function of the experimental factors chosen, which affect supply chain environmental performance.

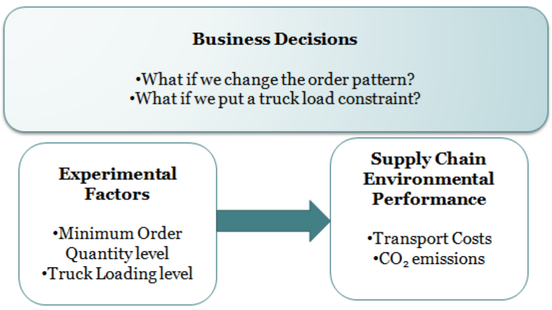

Figure 5 – Conceptual Model of this paper

5.4 Experimental Design

A designed factorial experiment is carried out to indicate the relative importance of the two experimental factors. As mentioned above, the performance measures examined are transport costs and CO_2 emissions and the two factors acting as independent variables are minimum order quantity constraint set and level of truck loading.

Having many possible experiments to test the research hypotheses, we had to decide on a specific experiment setting. Regarding the level of Minimum Order Quantity constraint, this paper examines three different levels: the no MOQ constraint set, the MOQ set to 2 pallets and the MOQ set to 6 pallets per order. The first level is chosen as the basis scenario (it is adopted in the AS-IS situation) and the others are chosen after the detailed examination of the data.

The current practice used in our simulation model is that no minimum truck load is needed in order for a transport to start. It is possible that trucks begin even with the load of a carton. This happens because the relevant parameter of "minimum quantity to start transport" constraint is not currently used. However, the fact is that the orders are ordinarily done in a way that ensures the truck saturation to a significant level. This paper incorporates two different levels: the setting of no full truck constraint and its setting to 90% of the truck's capacity. These two cases were also selected based on this detailed data examination.

Combining all the levels of the two factors, this leads to a total of 2X3 factorial experiments as shown in Table 1. This table provides the design matrix of our experiments.

	No MOQ needed	***MOQ=2***	***MOQ=6***
No need of minimum truck load to start transportation	Experiment 1 (AS-IS)	Experiment 3	Experiment 5
90% minimum truck load to start transportation	Experiment 2	Experiment 4	Experiment 6

Table 1 – Experiments to be tested

Transformation Process

For these experiments, the order data have been transformed in order to give the three different input datasets.

The first dataset, which depicts the AS-IS situation, was not been transformed at all. However, the two other datasets have been under transformation. The order lines and their quantities have been changed in a way to ensure that all orders are under the Minimum Order Quantity Constraint. This means that the total quantity of all the ordered SKUs is in an order is in multiples of the MOQ.

In order to achieve this, the following rules have been pursued:

1. Add products that have been removed from a previous order (in order to maintain the balance)
2. Add pallets in the most "fast-selling" product
3. Add fast-selling products that do not exist in this order

5.5 Description of the Scenarios

AS-IS scenario: In the AS-IS scenario, no changes in the order dataset are made. All orders made by the two model's Customers remain as they are and no other parameters are tested.

AS-IS scenario with truck saturation constraint: In this case, all the configuration data remain as in the AS-IS scenario, but a minimum quantity to start transport is set up to 90%.

MOQ = 2 scenario: In this scenario, the configuration data remain as in the AS-IS situation and the order dataset has been transformed in order to ensure the set of the minimum order quantity constraint to two pallets per order. The total of X orders for the first and Y orders for the second customer are restructured to C and F respectively.

MOQ = 2 scenario with full truck constraint: This scenario does not have any differences from the above one, except from the truck saturation constraint that is set up to 90%.

MOQ = 6 scenario: The order dataset has been transformed in order to ensure the set of the minimum order quantity constraint to six pallets per order.

MOQ = 6 scenario with full truck constraint: Same as the above, but the truck saturation constraint is set up to 90%.

6 Simulation Outputs

6.1 Basic statistics

The differences existing among the scenarios have given plenty differentiations among the results. The two selected local warehouses give two different eligible routes for the deliveries: either PS → local R's warehouse, or PS → DC → local R's warehouse.

In any case, we have decided to focus on two basic result groups: transport costs and CO_2 emissions. These results are presented below.

6.2 Results Regarding Transport Costs

The six experiments have given different results regarding the transport costs. Figure 6 depicts the transport costs results graphically.

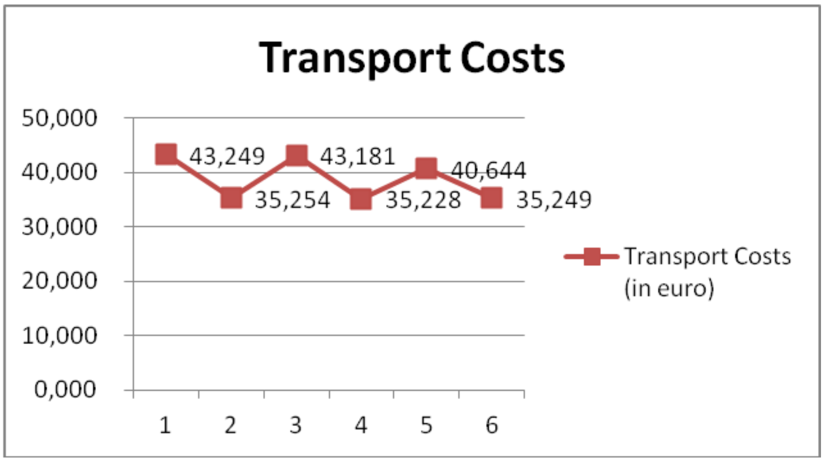

Figure 6 – Transport costs

As it seems from the Figure 9, in the case of the Truck Saturation Constraint the transport costs are decreased by about 18.5%. This percentage becomes bigger, if one takes under consideration the limitations of the simulation as described in the next section. On the one hand, this experimental factor cannot be implemented in the whole supply chain (but only in the PS→DC part). On the other, although this was not used before as a parameter of the supply chain, order were put in a way that somehow ensured truck saturation largely. Thus, the impact of this factor on the transport costs is extremely high.

The MOQ constraints seems also to affect the transport costs, but in a small percentage (about 6% decrease comparing the AS-IS and the MOQ = 6 situations). However, this decrease comes only from the small customer and, thus, it is quite significant. This is because the orders of the bigger customer were much bigger and already place in a way that diminishes this effect.

6.3 Results Regarding CO_2 Emissions

Figure 7 gives a graphical depiction of the CO2 emissions results.

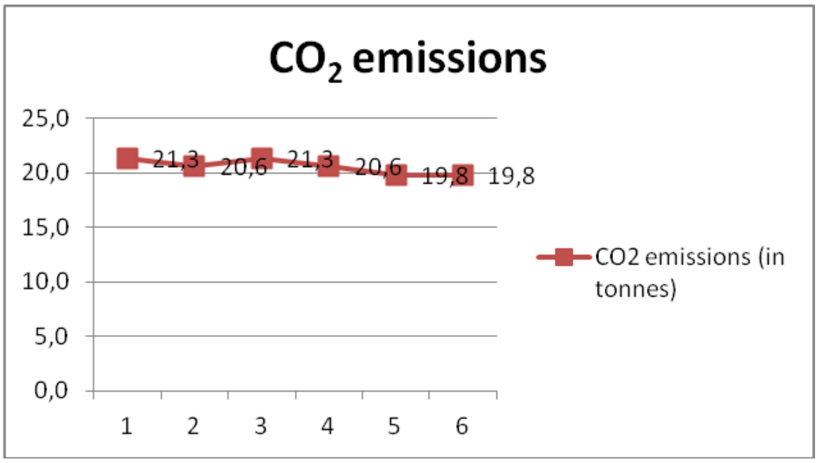

Figure 7 - CO_2 emissions

As in the case of the transport costs, CO_2 emissions are subject to the same simulation and model limitations. The decrease seems to be only about 4%, but in fact this is quite bigger. Both the MOQ and the truck saturation constraints affect significantly the model.

6.4 Concluding Remarks

Having reporting the abovementioned findings from the simulation experimentation, in this section we are going to add some concluding remarks.

As mentioned above, one of the selected customers is serviced via DC and the other directly from PS. However, due to a limitation of the simulation model, the truck saturation constraint is only applied to the PS → DC part of the supply chain. Thus, the results presented in the previous section are subject to these constraints. Nevertheless, if we take into account only this part of the supply chain, or, even better, if it was possible for this constraint to be applied to the whole supply chain the differences will be huge.

7 Conclusions

As it may have been obvious, the data manipulated and the simulation model provides some limitations, which may give ground to future research. Orders were already made in a way that diminishes the impact of the full truck constraint and this was only applied into the PS →DC part of the supply chain. As a consequence the differences in the outputs are given only by this part and are much more important than they seem to be. In addition, that's the reason why the truck saturation constraints in experiments 2, 4 and 6 do not give any significant differences no matter what the dataset is. Moreover, the small R's customer is a small one and its demand does not exceed the MOQ set as the limit for deliveries between PS and DC.

In addition, no outbound inventory and output service level were measured in our model's customers, so the impact of the MOQ and truck saturation constraint to the final customer was not easy to be seen. Furthermore, two levels of the vertical supply chain were missing. We only have information from the plant to the local retailer warehouses. However, if we had the data about the local retailer's stores and the final customer demand, we would have been able to have many important metrics, such as the inventory and the service level. Finally, only two warehouses have been used in the experiments, so no statistical analysis of the results has been possible.

These limitations urge us to continue to this research field and try to run more experiments within and out of this project. This future research could not only take into consideration the absence of the data from the experiments tested, but also try to design more business scenarios to be tried out.

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